Naval Health Research Center

ANNOTATED BIBLIOGRAPHY FOR GAS MASK AND CHEMICAL DEFENSE GEAR RELATED PAPERS

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NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
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INTRODUCTION

The vastly increased Soviet and Warsaw Pact chemical warfare threat and battlefield scenarios, which call for sustained application of force, direct the development of special technologies. The United States Army, as the Department of Defense's Executive Agent for Nuclear Biological Chemical (NBC) research, development, testing, and evaluation, is responsible for meeting these service requirements.

The Tri-Service Joint Working Group on Drug Dependent Degradation of Military Performance (JWGD3 MILPERF) was established by Research Area V at the United States Army Medical Research and Development Command, Fort Detrick, Frederick, Maryland. The JWGD3's purpose is to develop the methods and systems for assessing how pre-treatment and/or antidote prescribed drugs will affect military performance in chemical warfare situations.

The Naval Health Research Center's (NHRC) contracted involvement in the program has been to address performance effects due to MOPP4 protective clothing with and without pre-treatment antidote chemical defense prescribed drugs during sustained operations. A series of laboratory based, quasi-experimental studies with Marine Corps subjects is underway to measure performance degradation associated with pulmonary and heat stress, heavy physical work, sleep loss, and, eventually, NBC protective drugs. The Tri-Service Physiological and Cognitive Performance Assessment Batteries (PAB's) are used in these studies to provide standardized measures and data sets comprehensive to a Tri-Service Community.

Our group has done extensive literature reviews in the process of planning research protocols and preparing reports. This bibliography includes 104 military and other reports involving gas masks and/or other chemical defense gear, along with a few related pulmonary papers. The most recent searches were done in mid 1987. Where only part of a report was relevant to our laboratory, only that part was abstracted.

MASKS AND RELATED RESPIRATORY PAPERS (Also see the MOPP Gear section.)

Atterbom, H. A. and Mossman, P. B. (1978). Physiologic effects on work performance of vapor-barrier clothing and full-face respirator. Journal of Occupational Medicine, 20, 45-52.

See MOPP gear section for clothing effects. Wearing a full-face mask caused a fairly persistent increase in resting heart rate of 4 to 9 bpm.

Balieu, E. (1975). Respiratory protective devices. Leakage and total protection. Ugeskrift Laeger, 137, 1331-1335.

(Note: The following is based on the English abstract of a foreign language report.) Leakage can be measured quantitatively by placing a test subject in an atmosphere containing a known concentration of a harmless test aerosol or gas and subsequent analysis of the concentration inside the mask. Qualitative tests where the wearer judges the fit from the smell of some irritant gas are often used but can be misleading. The facial characteristics of the wearer (e.g. size or beard), as well as type and construction of the mask, affect fit. Some people can not be properly fitted with masks and should never use them.

Billups, N. B. and Oberst, F. W. (1965). Chloropicrin leakage test of the M17 protective mask equipped with drinking and resuscitation devices worn by volunteers (CDRL Technical Memorandum No. 2-32). MD: Army Edgewood Arsenal.

The M17 mask (E13R13 Field Protective Mask variation) worn with M6 hood underwent 192 trials involving rest, exercise, drinking water (via E49 device), and repeated connection of an E50 resuscitation tube. Two small size masks and 4 medium were used in these trials. The masks were checked and adjusted by an expert for proper fitting prior to each test. Three leaks were detected, two during attachment of the resuscitation tube and one during bending down exercises due to poor adjustment of the head harness.

Bouhuys, A., Jonsson, R., and Lundin, G. (1957). Influence of added dead space on pulmonary ventilation. Acta Physiologica Scandinavica, 39, 105-120.

The effect of an extra 260 or 480 ml of dead space on ventilatory efficiency was studied in 15 experimental trials on 5 normal subjects. The indices used were the percent nitrogen clearance delay and the lung clearance index. They found an average increase in tidal volume equivalent to the added dead space with no consistent change in respiratory rate or functional residual volume. There was a slowing of the nitrogen wash-out process but a suggestion of more uniform ventilation. The efficiency of the lungs proper was not impaired.

Burgin, W. W., Gehring, L. M., and Bell, T. L. (1982). A chemical field resuscitation device. Military Medicine, 147, 873-876.

Current chemical defense gear allows only for mask to mouth resuscitation utilizing a snorkle device. This technique is very tiring for the rescuer, requires the patient to be unmasked, and requires the patient to be supine. The authors have developed an adaptor which fits into the filter inlet of the victims mask and allows attachment of a hand held resuscitator. This, along with a balloon valve which can occlude the exhalation port of the mask during forced inhalation and open it during exhalation, was found to allow adequate forced ventilation under contaminated air conditions when tested with a simulated head and lungs. The Burgin Adapter can be used with all American masks and one British mask.

Cerrtelli, P., Sikand, R. S., and Farhi, L. E. (1969). Effect of increased airway resistance on ventilation and gas exchange during exercise. Journal of Applied Physiology, 27, 597-600.

The effects of breathing against increased resistances while performing graded exercise on a treadmill were studied in two trained subjects. At any exertion level the minute volume decreased as resistance was raised. The maximum oxygen uptake and exercise tolerance were stated to be decreased although details as to how much were not given. The relation

ship between oxygen consumption and workload below maximal level was unchanged.

Cherniack, R. M. and Raber, M. B. (1972). Normal standards for ventilatory function using an automated wedge spirometer. American Review of Respiratory Disease, 106, 38-46.

This is one of the most widely accepted sources for normal spirometry prediction standards. Tests were run using a wedge spirometer on 879 male and 452 female healthy nonsmokers living in a pollution-free area. Prediction equations were derived for males and females based on age and height for vital capacity, maximal mid expiratory flow, forced expiratory volume in one second, and indirect maximal breathing capacity. (Note: these are the standards used by NHRC.)

Cotes, J. E. (1962). Physiological aspects of respirator design. In Davies, C. N. (ed) Design and Use of Respirators (pp. 32-47). New York: MacMillan.

This is a review article. The author points out that half-face masks have less weight, deadspace, interference with perspiration, and restriction of vision, but full-face masks are easier to fit. Masks cause increased resistance to breathing which may be less well tolerated by older workers. Oxygen enrichment of the inspired gas is needed when the subject is in an oxygen reduced atmosphere. 50% rather than 100% oxygen is probably preferable, and the gas should be humidified. Masks can cause uncomfortable heating of the face and may contribute to general over heating secondary to interference with heat loss by evaporation from the lungs. Future developments should include lower resistance to breathing, better systems for sizing the face and assessing mask fit, and a wider range of mask sizes. Improved materials for mask construction are being developed.

Craig, F. N., Blevins, W. V., and Cummings, E. G. (1970). Exhausting work limited by external resistance and inhalation of carbon dioxide. Journal of Applied Physiology, 29, 847-851.

Twelve enlisted Army men performed graded treadmill exercise while wearing an M9 protective mask which was adapted to provide various inspiratory and expiratory resistances. They performed similar exercise while breathing increased concentrations of carbon dioxide. Increased resistance had a greater effect on endurance in easy tasks than more difficult tasks (those leading to exhaustion in less than 5 minutes). Resistance did not effect the oxygen debt at exhaustion. Carbon dioxide concentrations of more than 4.0% decreased endurance more than combined inspiratory and expiratory resistances of 15.5 and 2.0 cm H20/l/sec respectively did, while concentrations less than 3.9% had less effect than this resistance combination. (Note: There were only 2 trials at concentrations above 4.0%.) As exercise progressed breathing frequency increased with duration of inspiration being conserved at the expense of duration of expiration. A limiting factor at exhaustion appeared to be that time for expiration approached a minimum value.

Craig, F. N., Blevins, W. V., and Froehlich, H. L. (1971). *Training to improve endurance in exhausting work of men wearing protective masks: a review and some preliminary experiments* (Technical Report No. 4535). MD: Edgewood Arsenal.

Eight relatively unfit subjects performed treadmill walking to exhaustion with and without modified M17 or M9 masks. Tests were performed before and after 3 to 8 sessions of practice in hard work with high inspiratory resistance. Even without filters, wearing a mask facepiece had a degrading effect on endurance. The practice sessions failed to reduce the decrements in endurance caused by increased resistances.

de V. Martin, H. (1972). The effect of training and a mask on the voluntary endurance time of men exercising in the heat. *Journal of Physiology (London)*, *229*, 39P-40P.

Subjects performed maximal bicycle ergometer tests with and without the NBC S6 respirator over a period of 5 weeks in a dry bulb/wet bulb temperature of 35/25°C. The mask decreased endurance times ($p<.05$) and appeared to lower the voluntary tolerance of raised body temperature.

Training improved endurance times both with and without the mask but did not eliminate the decrement attributable to the mask.

de V. Martin, H. and Goldman, R. F. (1972). Comparison of physical, biophysical, and physiological methods of evaluating the thermal stress associated with wearing protective clothing. Ergonomics 15, 337-342.

The effect of wearing the M17 gas mask with army fatigues or 3 different chemical defense outfits was to insignificantly increase the sweat rate and to reduce evaporation by 8% ($p<.01$). (Note: See MOPP bibliography for more complete summary of this study.)

Demedts, M. and Anthonisen, N. R. (1973). Effects of increased external airway resistance during steady-state exercise. Journal of Applied Physiology, 35, 361-366.

Six males performed pulmonary function tests and bicycle exercise at various loads. The effects of the addition of 3 resistances to the breathing circuit was examined. Added resistance did not change mean oxygen consumptions. Higher resistances significantly limited maximum breathing capacity (MBC) and maximum exercise ventilation at a given resistance was 65-75% of the 15-sec MBC measured at that resistance.

Dukes-Dobos, R. J. and Smith, R. (1984). Effects of respirators under heat/work conditions. American Industrial Hygiene Association Journal, 45, 399-404.

Five unacclimatized male subjects performed 1 hour treadmill walks at high and low work levels, at 25° or 43.3°C, with and without full- and half-mask respirators. The full mask consistently increased heart rate by 7-8 beats per minute (only significant under low heat conditions), elevated energy expenditure, elevated oral temperature in the high work high temperature condition, and elevated oxygen consumption. Both masks caused increased minute ventilation with the greatest increases seen in the full mask high work combinations (high or low heat). (Note: the minute ventilation results differ from most other studies.)

Epstein, Y., Keren, G., Lerman, Y., and Shefer A. (1982). Physiological and psychological adaptation to respiratory protective devices. Aviation Space and Environmental Medicine, 53, 663-665.

Twenty subjects were tested at 80% of their maximal oxygen consumption for 6 consecutive days while wearing a respiratory protective device with a resistance of 2.80 ± 0.07 cm H20/1/sec. Subjects reported no changes in subjective feelings but there was evidence of physiological adaptations. Respiratory rate increased, inspiratory/expiratory ratio dropped, peak inspiratory pressure decreased, and external respiratory work increased over the 6 days.

Flook, V. and Kelman, G. R. (1973). Submaximal exercise with increased inspiratory resistance to breathing. Journal of Applied Physiology, 35, 379-384.

Eleven very fit 16-year-old junior soldiers performed bicycle exercise at graded work rates while breathing through various resistances. There were minimal changes in heart rate, oxygen consumption, and endurance, but there was progressive hypoventilation and lengthening of inspiration with increasing resistance.

Folinsbee L. J., Wallace, E. S., Bedi, J. F., and Horvath, S. M. (1983). Exercise respiratory pattern in elite cyclists and sedentary subjects. Medicine and Science in Sports and Exercise, 15, 503-509.

Seven elite male cyclists were compared to 10 sedentary males. The cyclists had significantly higher maximal oxygen consumptions but non significantly higher forced vital capacities, forced expiratory volumes in 1 minute, and maximum voluntary ventilations (MVV). During maximal bicycle exercise cyclists achieved significantly greater maximum ventilation (183 vs 136 l/min BTPS, $p < .01$) and CO2 production (5.86 vs 4.23 l/min STPD, $p < .01$) using a markedly higher percentage of their resting MVVs (89 vs 71%). They did this by increasing respiratory frequency rather than changing tidal volume. Expiratory time was reduced more than inspiratory time.

Fridriksson, H. V., Malmberg, P., Hedenstrom, H., and Hillerdal, G. (1981). Reference values for respiratory function tests in males: prediction formulas with tobacco smoking parameters. Clinical Physiology, 1, 349-364.

> Prediction equations based on age, height, weight, smoking years, and smoking intensity were derived for many respiratory function tests using multiple regression of data from 263 healthy males. (Note: This is not a commonly used source of 'normal' values and cannot be used on our population as we do not have detailed smoking histories.)

Gamberale, F., Holmer, I., Kindblom, A. -S. and Nordstrom, A. (1978). Magnitude perception of added inspiratory resistance during steady-state exercise. Ergonomics, 21, 531-538.

> Eleven healthy males performed steady-state bicycle exercise while breathing at each of 6 added inspiratory resistances. Increased resistance caused decreased ventilation and prolonged inhalation. There was a linear relationship between perceived and actual respiratory resistance.

Gee, J. B. L., Burton, G., Vassallo, C., and Gregg, J. (1968). Effects of external airway obstruction on work capacity and pulmonary gas exchange. American Review of Respiratory Disease, 98, 1003-1012.

> Physical education students performed progressive bicycle exercise with and without external expiratory, inspiratory, or combined obstruction (resistance=5cm H20/l/sec) in a randomized crossover design. The 3 types of obstruction caused equivalent degrees of hypoventilation which progressed as the workload increased. Expiratory obstruction tended to produce a decreased tidal volume while inspiratory or combined resistance reduced respiratory frequency. The combined obstruction caused a 30% decrease in maximum breathing capacity but caused no reduction in oxygen consumption (V02), C02 production, or heart rate during exercise requiring 86% of maximal V02.

Hedenstierna, G., Jorfeldt, L., and Bygdeman, S. (1981). Flow-volume curves in healthy non-smokers and in smokers. Clinical Physiology, 1, 339-348.

Maximum expiratory flow-volume curves were recorded in healthy male and female smokers and non-smokers. Maximum expiratory flow rates at 25% and 50% of vital capacity tended to be lower in smokers especially males, but the overlap was large. Equations developed to predict these parameters and peak expiratory flow based on sex and age were fairly inaccurate and inclusion of height and weight did not improve prediction.

Harber, P., Tamimie, R. J., Bhattacharya, A., and Barber, M. (1982). Physiologic effects of respirator dead space and resistance loading. Journal of Occupational Medicine, 24, 681-684.

Seven males and 2 females were tested at rest and during low level bicycle exercise (exercise intensities were selected by the subjects) with and without added 4.9 cm H20/l/sec inspiratory resistance and/or 300 ml dead space. Maximal exercise tests were performed with the added dead space and resistance. During the low level exercise, inspiratory resistance caused decreased respiratory rate, tidal volume, and minute ventilation, while dead space caused increased tidal volume and minute ventilation. Maximal testing showed that respiratory rate, tidal volume, and minute volume still had reserve response left despite the effects of added resistance or dead space.

Harber, P., Tamimie, J., Emory, J., Bhattacharya, A., and Barber, A. (1984). Effects of exercise using industrial respirators. American Industrial Hygiene Association Journal, 45, 603-609.

Ten normal volunteers performed bicycle exercise with and without inspiratory resistance and dead space loading. The respiratory loading caused increasing inspiratory work with the greatest magnitude effects at the higher exercise levels. Inspiratory time was increased by respirator load but decreased by exercise. Oxygen consumption and heart rate were not affected by respirator load.

Hardis, K. E., Cadena, C. A., Carlson, G. J., da Roza, R. A., and Held, B. J. (1983). Correlation of qualitative and quantitative results from testing respirator fit. American Industrial Hygiene Association Journal, 44, 78-87.

Three qualitative respirator fit tests: the negative pressure test, the isoamyl acetate test, and the irritant smoke test were performed concurrently with a quantitative fit test (the dioctylphthalate (DOP) test) with half and full facepiece masks. The 95% of the test population with adequate fit based on the DOP test passed the qualitative tests 96 to 100% of the time. The 5% of subjects with inadequate fit failed the qualitative tests 93 to 100% of the time. Twenty-three to 46% of the poorly fitting full face masks were detected by qualitative methods. It is noted that the small number of subjects with poor fit decreases the certainty of these results.

Hermansen, L., Vokac, Z., and Lereim, P. (1972). Respiratory and circulatory response to added air flow resistance during exercise. Ergonomics, 15, 15-24.

Ten healthy subjects performed bicycle exercise at submaximal and maximal work loads with and without an M9 gas mask. The mask lowered pulmonary ventilation especially at the higher workloads (a decrease of 43% at maximal workload) secondary to a decreased respiratory rate partially compensated for by an increased tidal volume. Oxygen uptake was unchanged at submaximal loads but decreased during maximal work. Heart rate was increased at submaximal loads but unchanged at maximum. It is not stated whether maximal workload decreased.

Hey, E. N., Lloyd, B. B., Cunningham, D. J. C., Jukes, M. G. M., and Bolton, D. P. G. (1966). Effects of various respiratory stimuli on the depth and frequency of breathing in man. Respiratory Physiology, 1, 193-205.

There is a linear relation between pulmonary ventilation (VE) and tidal volume (VT), during quiet breathing and hyperventilation, up to a VT of about half the vital capacity, VE m(VT K). The constant K is similar between subjects while m varies from subject to subject. Further increases in VE occur through increased frequency rather than increased VT. The relation is not changed by wide variations in PACO2 or PAO2, by metabolic acidosis, some drugs which affect respiration, and by moderate

muscular exercise. Elevated body temperature increases respiratory frequency and the parameter m.

Hill, A. R., Kaiser, D. L., Lu, J-Y., and Rochester, D. F. (1985). Steady-state response of conscious man to small expiratory resistive loads. Respiratory Physiology, 61, 369-381.

Breathing patterns and abdominal muscle activity were recorded on 7 subjects while they breathed against expiratory resistances of 0 to 10 cm H2O/L/sec with and without augmented dead space or treadmill walking. Increased resistance increased expiratory time, tidal volume, and mean inspiratory flow rate, while decreasing respiratory frequency. These changes were less apparent when minute ventilation was increased secondary to dead space or exercise. Minute ventilation and abdominal muscle activity were not affected by the increased resistance.

Im Hof, V., West, P., and Younes, M. (1986). Steady-state response of normal subjects to inspiratory resistive load. Journal of Applied Physiology, 60, 1471-1481.

The respiratory driving pressure waveform during steady-state unloaded and loaded (8.5 cm H2O/l/sec) breathing in 8 subjects was calculated using the method of Younes et al. (J.Appl.Physiol. 51:963-989, 1981). Tidal volume during resistance breathing was 108% of control. This increase was accomplished through an increase in peak amplitude, an increase in the duration of the rising phase, and a more concave shape of the rising phase.

Johnson, A. T. (1976). The energetics of mask wear. American Industrial Hygiene Association Journal, 76, 479-488.

Two healthy subjects performed bicycle exercise at steady work rates while wearing M17 masks (reported mask resistances: inspiratory 3.4 cm H2O/l/sec, expiratory 1.3 cm H2O/s/sec). At low work levels (<250 watts) endurance appeared to be limited by elevation of core temperature. At high work levels (275-400 watts) the limiting factor was decreasing duration of exhalation.

Johnson, A. T. and Masaitis, C. (1974). Prediction of inhalation time/ exhalation time ratio during exercise. IEEE Transactions on Biomedical Engineering, BME-23, 376-380.

An expression was derived for prediction of the inhalation time/exhalation time ratio using a criterion of minimization of total respiratory work during a complete respiratory cycle. Calculated results compared well with experimental data. The expression predicted a rectangular waveshape during exercise, which agreed with previously published experimental and theoretical findings.

Johnson, A. T. and McCuen, R. H. (1981). Prediction of respiratory period on men exercising while wearing masks. American Industrial Hygiene Association Journal, 42, 707-710.

"Four competing models were developed to test assumptions about the workings of the respiratory controller. These models were tested against previously published data and unknown parameters estimated with a least-squares procedure. It was found that similar fits were obtained on data from men not at exhaustion by minimizing total respiratory power or inspiratory power only. Inspiratory power alone gave good fit at exhaustion. Also, mask resistance was found to be unequivalent to respiratory resistance in determination of respiratory period."

Johnson, A. T. and Micelli, T. M. (1973) Flow regimes in protective masks (Technical Report No 4712). MD: Edgewood Arsenal.

M28, M17, and M9 masks were tested at various air flow rates, on human subjects and on a head form. The M9 mask showed turbulence at high rates of flow on the head form. The M17 mask showed turbulence at higher rates of flow (above 100 liters/minute) on some, but not all, humans subjects. The turbulence related to collapse of the nose cup and stiffening the nose cup delayed onset of turbulence. Turbulence prolongs inspiratory

time leaving less time for expiration and reducing tolerance time of men working while wearing the mask.

Johnson, R. F. and Sleeper, L. A. (1986) Effects of chemical protective handwear and headgear on manual dexterity. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 994-997). Santa Monica, CA: Human Factors Society.

Manual dexterity was reduced and learning of manual tasks was slower under gloved conditions than with bare hands. Wearing the M17A1 gas mask had no effect on performance.

Kolesar, E. S., Cosgrove, D. J., de la Barre, C. M., and Theis, C. F. (1982). Comparison of respirator protection factors measured by two quantitative fit test methods. Aviation, Space, and Environmental Medicine, 53, 1116-1122.

The Army XM-29 chemical warfare defense respirator was tested with two quantitative techniques. The sodium chloride solid aerosol challenge method was found to be more sensitive than the di-2-ethylhexyl phthalate liquid aerosol challenge.

Kory, R. C., Callahan, R., and Boren, H. G. (1961). The Veterans Administration-Army cooperative study of pulmonary function.: I. Clinical spirometry in normal men. American Journal of Medicine, 30, 243-258.

A total of 468 male hospital employees, patients, medical students, residents and physicians with no history or other evidence of any disease which could be expected to affect pulmonary function were studied. Smokers were not excluded. Spirometric measurements were made on adapted Collins 13.5 L recording spirometers. Prediction formulas based on age and height were derived for vital capacity, maximum voluntary ventilation (MVV), forced expiratory volume at 0.5 second, and forced expiratory volume at 1 second. (Note: This study measured actual MVV and got much higher values than Cherniak and Raber who used estimated MVV. (Our lab uses actual measurements and our subjects have showed values closer to this study than to those predicted by Cherniak and Raber's formula.)

Lerman, Y., Shefer, A., Epstein, Y., and Keren, G. (1983). External inspiratory resistance of protective respiratory devices: effects on physical performance and respiratory function. American Journal of Industrial Medicine, 4, 733-740.

Twenty subjects ran on a treadmill at a work rate equivalent to 80% of maximal oxygen uptake while breathing through a device with low expiratory resistance and various inspiratory resistances. Increasing inspiratory resistance was found to decrease tidal volume, endurance, and maximal heart rate, while increasing the ratio of inspiration to expiration time, peak inspiratory pressure and CO_2 retention. Difficulty in inspiration was the main reason subjects gave for terminating a treadmill test.

Louhevaara, V. A. (1984). Physiological effects associated with the use of respiratory protective devices. A review. Scandinavian Journal of Work and Environmental Health, 10, 275-281.

This is a review of 65 articles. It has been found that added inspiratory resistance decreases breathing frequency and prolongs inspiratory time in younger subjects while decreasing tidal volume, oxygen consumption, and carbon dioxide production in older subjects. Expiratory resistance decreases ventilation rate. It initially decreases oxygen consumption and carbon dioxide production, but these subsequently return to normal, with continued submaximal exercise. Combined inspiratory and expiratory resistance decreases ventilation rate at submaximal exercise levels and decreases oxygen consumption at near maximal levels. Dead space increases the ventilation rate proportionally. Extra weight increases ventilation rate, oxygen consumption, and heart rate at submaximal exercise levels, and decreases endurance. In general, filtering devices and air-line devices either: 1) Decrease breathing frequency, increase tidal volume, and adjust the length of the breathing cycles depending on distribution of added breathing resistance; or 2) Decrease tidal volume, with minimal changes in respiratory rate and the ratio of inspiratory to expiratory time. With a self-contained breathing apparatus the effects of added carrying weight and restricting harnesses are added to the breathing resistance effects.

Louhevaara, V., Smolander, J., Korhonen, O., and Tuomi, T. (1986). Effects of industrial respirators on breathing pattern at different work levels. European Journal of Applied Physiology, 55, 142-146.

Nine construction workers (ages 35-44) and nine firemen (21-35) were studied at rest and during submaximal ($\leq$60% VO2max) treadmill walks while wearing a low resistance breathing valve, a filtering half mask, or an air-line apparatus. The devices had no significant effects on inspiratory time, expiratory time, breathing frequency, tidal volume, or pulmonary ventilation. The breathing patterns of the construction workers and the firemen did differ significantly.

Louhevaara, V., Smolander, J., Tuomi, T., Korhonen, O., and Jaakkola, J. (1985). Effects of an SCBA on breathing pattern, gas exchange, and heart rate during exercise. Journal of Occupational Medicine, 27, 213-216.

The use of a self-contained breathing apparatus (SCBA) consistently limited tidal volume during sequential progressive treadmill exercise tests. Oxygen consumption and heart rate were increased during submaximal exercise. In 4 subjects who reached their maximal heart rate with the SCBA, mean ventilation rate was 68% and oxygen consumption was 83% of maximal values without the SCBA. The shoulder harness of the heavy device was thought to be a major factor interfering with ventilation and gas exchange.

Louhevaara, V., Tuomi, T., Korhonen, O., and Jaakkola, J. (1984). Cardiorespiratory effects of respiratory protective devices during exercise in well-trained men. European Journal of Applied Physiology, 52, 340-345.

Twelve well-trained firemen aged 21-35 were studied during submaximal treadmill walks with and without a filtering (predominantly inspiratory

resistance), an air-line (predominantly expiratory), or a self-contained breathing apparatus (SCBA) (predominantly expiratory). During higher work levels and recovery heart rate and oxygen consumption were increased by each of the devices. Although actual ventilation (l/min) tended to be increased (only significant at highest work level with the SCBA), there was relative hypoventilation (decrease in the volume expired relative to the oxygen consumed) and a decrease in the respiratory quotient with all of the devices. Maximal effects were seen with the self-contained breathing apparatus. The increased ventilation results differ from previous gas mask studies. Good physical conditioning and extensive experience wearing respirators are suggested as explanations for this. (However, see reference 13, Dukes-Dobos.)

Louhevaara, V., Tuomi, T., Smolander, J., Korhonen, O., Tossavainen, A., and Jaakkaola, J. (1985). Cardiorespiratory strain in jobs that require respiratory protection. International Archives of Occupational and Environmental Health, 55, 195-206.

The heart rates, oxygen consumptions, and ventilation rates of thirty workmen and firemen were studied while they were wearing a variety of respirators in the course of their usual work. These were compared to maximal heart rate and oxygen consumption (VO2max) estimated from submaximal bicycle ergometry performed without the respirators. Workers using filtering or air line devices showed mean heart rates of 66 to 132 BPM, with oxygen consumptions of 12 to 62% of VO2max and ventilation rates of 16 to 48 l/min. It was recommended that continuous use of either type of respirator be limited to less than 30 minutes. Working with the added weight of a self-contained breathing apparatus produced mean heart rates of 142 to 160 BPM, estimated oxygen consumptions of 54 to 74% of VO2max, and ventilation rates of 45 to 70 l/min. This required good physical fitness. It was suggested that workers required to use SCBA should have a minimal VO2max of 3 liters/min.

Love R. G. (1980). Acceptable breathing resistance for respirator use. In Papers From the NIOSH International Respirator Research Workshop, (pp. 181-202). Morgantown, WV: National Inst. for Occupational Safety and Health.

This paper refers to 31 previous studies in discussing the amount of breathing resistance that is: "physiologically first detectable" (1 cm H20 at 100 l/min), "first subjectively noticeable" (.59 - .87 cm H20 l/sec), "noticeable but tolerable" (about 15 cm H20 at maximal flow), and "only just tolerable" (283 cm H20/l/sec, for flow resistive (viscous) resistance). He concludes that total breathing resistance should be kept around 12 - 17 cm H20 with inspiratory resistance of 6 - 14 cm H20.

Love, R. G., Muir, D. C. F., Sweetland, K. F., Bentley, R. A., and Griffin, O. G. (1977). Acceptable levels for the breathing resistances of respiratory apparatus: results for men over the age of 45. *British Journal of Industrial Medicine*, *34*, 126-129.

Peak inspiratory pressure, external respiratory work rate, ventilation, and gas exchange were measured in 41 older coalworkers walking on a treadmill with and without various inspiratory resistances. Increased resistance led to reduced minute volume, oxygen uptake, and carbon dioxide elimination. Breathing frequency was unchanged. At the workload studied (walking 70 m/min up a 9% incline for 15 minutes without resistance followed by 15 minutes with), these workers were able to tolerate the same inspiratory resistances as younger men.

Luria, S. M. and Dougherty, H. H. (1983). *Effectiveness of the Mark V chemical-biological mask worn over spectacles* (NSMRL Report No. 1006). Groton, CT: Naval Submarine Medical Research Laboratory.

Standard S-10 Navy issue, Sampson P-3 gold wire, Sampson P-3 matte chrome, and Combat frames were tested in the Mark V mask on bearded and unbearded individuals using helium as the test gas. Without frames, about 2% of the helium leaked in with unbearded subjects and about 8% with beards. Standard S-10 frames caused 100% leakage in all subjects. The best frame was the Sampson P-3 gold wire which caused 5.47% leakage in clean-shaven and 12.07% in bearded. The standard frames were the most uncomfortable with the mask; the P-3 frames were the least uncomfortable.

Luria, S. M. and Dougherty, J. H. (1984). Leakage into the navy oxygen breathing apparatus when worn over spectacles (Report No. 1029). Groton, CT: Naval Submarine Medical Research Laboratory.

The Navy mask was tested over the same frames used in the preceding study as well as with the OBA spectacle insert. The S-10 frame caused 100% leakage, but the other frames increased leakage by less than 1%, with the combat frame performing best.

McKerrow, C. B. (1955). Ventilatory Capacity. Unpublished M.D. Thesis, Cambridge University, England. As cited by Cotes J. E. (1961) Physiological Aspects of Respirator Design. In Davies, C. N. (ed.) (1962). Design and Use of Respirators. Proceedings of a Joint Meeting of the Ergonomics Research Society and the British Occupational Hygiene Society, held at Porton, 5 and 6 July, 1961, page 36. New York: MacMillan.

This researcher tried to define the resistance level sufficient to reduce maximum breathing capacity (MBC). An apparatus with resistance of about 2 cm H20 at 150 1/min flow and about 5 cm H20 at 250 1/min significantly reduced the MBC of 7 normal subjects.

Mahler, D. A., Moritz, E. D., and Loke, J. (1982). Ventilatory responses at rest and during exercise in marathon runners. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, 52, 388-392.

Twenty male marathon runners were compared to twenty non-conditioned non-smoker control subjects as to their ventilatory responses to hypercapnia and hypoxia at rest and ventilatory equivalents for carbon dioxide and oxygen during exercise. No differences were found. Additionally, all subjects underwent standard pulmonary function testing. There were no differences between runners and controls on forced vital capacity (FVC), total lung capacity, forced expiratory volume in 1 minute (FEV1), FEV1/FVC, maximal expiratory flow at mid expiration, maximal voluntary ventilation (MVV), or lung diffusion capacity for carbon monoxide. (Note: Using the standard Cherniak-Raber prediction formula for MVV on the mean ages and heights of the two groups gives underestimates approximately as great as those we found in our first batch of subjects in phase 1A.)

Morgan, W. P. (1983). Psychological problems associated with the wearing of industrial respirators: A review. American Industrial Hygiene Association Journal, 44, 671-676.

This is a review article with 26 references. "Willingness to wear and make proper use of respirators represents a significant problem." All respirators cause some degree of discomfort. Restriction of vision can cause anxiety and hyperventilation. Difficulty breathing and cumbersome equipment adds to the energy cost of exercise. Restriction of communication can be unpleasant and hazardous. The lack of immediate subjectively apparent effects from not wearing a device make it more difficult to convince workers to wear them even if long term or intermittent effects have been clearly demonstrated. "About 10 percent of any given group of test subjects experience an excessive amount of discomfort while wearing respirators." However, since most subjects are volunteers (high motivation) and healthy this may be an underestimate for the general population. Valid psychometric instrumentation did not exist at the time of publication for use in the identification of those individuals who are more prone to experience distress while wearing respirators, but research was underway.

Morgan, W. P. (1983). Psychometric correlates of respiration: A review. American Industrial Hygiene Association Journal, 44, 677-684.

A review article with 41 references.

Morris, J. F., Koski, A., and Johnson, L. C. (1971). Spirometric standards for healthy nonsmoking adults. American Review of Respiratory Disease, 103, 57-67.

This is one of the most commonly used sources for 'normal' standard values for pulmonary function tests. Measurements were taken on 988 healthy nonsmoking men and women ranging in age from 20 to 84.

Prediction formulas based on sex, age, and height were developed for forced vital capacity, forced expiratory volume in 1 minute, forced expiratory flow (FEF) at 25-75% of expiratory volume, and FEF at 200-1200cc. (Note: Our SensorMedics MMC Horizon System 4400 uses the last two of these prediction formulas. Cherniack and Raber formulas are used for the other tests.)

Muza S. R. (1986). *A review of biomedical aspects of CB masks and their relationship to military performance*. Unpublished manuscript.

A review article with 65 references. The most relevant citations are covered individually in this bibliography.

Raven, P. B. (1980). Clinical pulmonary function and the physiological effects of using industrial respirators. In *Papers from the NIOSH International Respirator Research Workshop* (pp. 203-45). Morgantown, WV: National Inst. for Occupational Safety and Health.

This study evaluated the effects of a full face mask respirator (inhalation resistance of 85 mm H_2O and exhalation resistance of 25 mm H_2O at 85 l/min flow) on the pulmonary function tests of 31 normal subjects and 29 subjects with impaired respiratory function. The mask significantly reduced forced inspiratory vital capacity and forced expiratory volume in 1 minute, but there was no significant interaction between impairment and mask wear. Measures of dynamic lung performance such as peak flow and maximum breathing capacity were decreased by the mask more in the normals than in the impaired subjects. When subjects performed treadmill exercise testing with and without the mask, the normals differed from the impaired in many measurements taken during exercise. During exercise, the mask increased end tidal CO_2, $FICO_2$, systolic blood pressure, and peak inspiratory pressure, while reducing peak inspiratory flow similarly in the two groups.

Raven, P. B. (1980). Respirator research: Where it needs to go. The man respirator interface. In *Papers from the NIOSH International Respirator Research Workshop* (pp. 51-65). Morgantown, WV: National Inst. for Occupational Safety and Health.

High priority research should include:

"a. Produce a regulator valve capable of following the true respiratory demands of the human.

b. Devise a dynamic flow/resistance calibrating pump.

c. Describe the psychophysiological responses of specific diseased populations to respirator wear during rest and work.

d. Provide a simple yet specific clinical test(s) which is response and job related.

e. Validate the predictability of the screening test(s).

f. Evaluate training programs.

g. Reduce the weight bearing load of the respirators to a minimum."

Raven, P. B., Dodson, A. T., and Davis, T. O. (1979). The physiological consequences of wearing industrial respirators: A review. <u>American Industrial Hygiene Association Journal</u>, <u>40</u>, 517-534.

A review with 45 references. The authors note the difficulty in making general conclusions about the great variety of available respirators. The most relevant papers are covered individually in this bibliography.

Raven, P. B., Moss, R. F., Page, K., Garmon, R., and Skaggs, B. (1981). Clinical pulmonary function and industrial respirator wear. <u>American Industrial Hygiene Association Journal</u>, <u>42</u>, 897-903.

Sixty subjects, 12 with superior, 37 with normal, and 11 with moderately impaired pulmonary function were evaluated with pulmonary function tests with and without a full face mask respirator (inspiratory resistance of 85 and expiratory resistance of 25 mm H_2O at 85 l/min flow). Tests which measure the effort dependent flow characteristics of the lung were most affected by the respirator. Peak flow, when subjects breathed room air, dropped by 15%, and maximum voluntary ventilation, measured over 15 seconds, dropped by 18 to 32% with the mask. The respirator affected the subjects with superior lung function more than those who were moderately impaired. It was suggested that "in severely obstructed subjects one could predict a slight improvement in lung function during respirator wear."

Rengstorff, R. G. (1980). Problems with optical inserts in military protective masks. *Military Medicine*, *145*, 334-337.

Almost 50% of U.S. Army personnel wear eye glasses but only 30% of glasses wearers have been issued optical inserts. Most optometry officers believe that more people should have inserts and that the inserts need major improvement to make them work better.

Savic, S., Dimitrijevic, B., and Mojovic, M. (1974). Respiratory functions during physical efforts with the use of gas mask. *Zbornik Vojnomedicinske Akademiie*, *1974*, 50-55.

(The following is based on the English summary of a foreign language report.) The effects of inspiratory resistance of 30 and expiratory resistance of 10 mm H20, at 30 l/min was studied. During exercise sufficient to raise the heart rate to 170 beats/min there was a decrease of minute volume, increased blood lactic acid concentration, and decreased respiratory rate. No effects were seen at lower levels of exercise.

Shephard, R. J. (1962). Ergonomics of the respirator. In Davies, C. N. (ed.) *Design and Use of Respirators* (pp. 51-66). New York: MacMillan.

The British service respirator hampers speech transmission and vision, causes sweat accumulation without significant heat storage, increases respiratory load by 70-75%, does not affect cardiac output or pulmonary resistance, decreases psychomotor performance by 2-10%, decreases maximal bicycle exercise by <4%, and decreases unpaced obstacle course performance by 8-9%. The main limitations of prolonged wearing come from subjective factors.

Silverman, L., Lee, G., Plotkin, T., Sawyers, L. A., and Yancey, A. R. (1951). Air flow measurements on human subjects with and without respiratory resistance at several work rates. *American Medical Association Archives of Industrial Hygiene Journal*, 3, 461-478.

Healthy male subjects were studied at rest and during bicycle exercise at various work levels. Measurements were made while subjects breathed against minimal resistance and while resistance was elevated (64 mm H2O inspiratory and 41 mm expiratory). At higher work levels increased resistance reduced oxygen consumption (a decrease of 168 ml/min at a work load of 1660 kg-m per minute), and reduced maximum air flow, and minute volume (by almost 20% each, at the highest work rates). Tidal volumes were not effected at work rates below 1,107 kg-m/min. Above that they tended to be decreased.

Skretvedt, O. T. and Loschiavo, J. G. (1984). Effect of facial hair on the face seal of negative-pressure respirators. Industrial Hygiene Association Journal, 45, 63-66.

Bearded subjects consistently failed a qualitative test (isoamyl acetate) for fit while wearing either half or full facepiece masks. Using a quantitative test (di(2-ethylhexyl) Phthalate) the median leakage was 8% in the half masks and 3% in the full masks for the bearded subjects, and .03% and <.01% respectively for the clean shaven subjects.

Spioch, F. M., Kobza, R., and Rump, S. (1962). The effects of respirators on the physiological reactions to physical effort. Acta Physiologica Polonica, 13, 637-649.

Ten healthy male subjects performed light (lifting the lever of a Zimmermann ergometer) or intensive (Harvard step-up test) exercise with or without a respirator (type and resistances not specified). They also underwent a psychotechnical examination (Bourdon test) with and without the mask. There were greater increases in arterial blood pressure, minute volume and stroke volume after the step-up test with the respirator than without. Subjects took longer to complete the Bourdon test and made more errors while wearing the mask. (Note: Very few studies have looked at the effects of a mask on non-exertional task performance. Also see Johnson and Sleeper.)

Stemler, F. W. and Craig, F. N. (1977). Effects of respiratory equipment on endurance in hard work. Journal of Applied Physiology: Respiratory, Environmental, and Exercise Physiology, 42, 28-32.

U.S. Army enlisted men ran at 11 km/hr on a 10% grade until unable to maintain the pace. They were studied wearing a variety of respiratory devices including the M17A1 mask (almost identical to the M17A2 mask that our lab has been working with). Endurance, final heart rate, and final respiratory frequency were reduced by all the masks (even an M9 mask modified by removal of facepiece and expiratory valve). There was a rather smooth relationship between increasing resistance and decreasing endurance. Average endurance decreased from 545 sec to 338 sec, with the M17A2 mask. They found a great variability in the expiratory phase at the end of the run (against the theory that a critically short expiratory time is the factor that limits exercise). (Note: This data was also presented in Edgewood Arsenal Technical Report No. 76040.)

Supinski, G. S., Levin, S., and Kelsen, S. G. (1986). Caffeine effect on respiratory muscle endurance and sense of effort during loaded breathing. Journal of Applied Physiology, 60, 2040-2047.

Caffeine (600 mg) was found to prolong respiratory muscle endurance during inspiratory threshold loading of various intensities. Caffeine also decreased the sense of effort during loaded breathing in 9 of 11 subjects. (Generally we have allowed subjects their normal caffeine intake in the meal prior to starting a study but none during the course of the study.)

Tabakin, B. S. and Hanson, J. S. (1960). Response to ventilatory obstruction during steady state exercise. Journal of Applied Physiology, 15, 579-582.

Five healthy male physicians performed steady state treadmill exercise while breathing against minimal resistance or with 2cm long rubber tubes added to the breathing circuit to provide moderate (internal diameter [illegible] mm) or high (5.0 mm) expiratory resistances. The obstructions were added during the 5th and 6th minutes of exercise after a steady state had been established. There was a non-significant trend for the moderate resistance to decrease the minute volume during the final two minutes of a six minute obstruction period as compared to the minimal resistance. With the high resistance minute volumes decreased significantly in the 1st minute after resistance was added and some degree of reduction was maintained throughout the period of increased resistance. Oxygen uptake and CO_2 elimination were significantly reduced in the first minute of high resistance. Oxygen uptake was no longer significantly reduced after 2 minutes, although there was a significant oxygen debt at the conclusion of the obstructed period. CO_2 elimination was significantly reduced for 6 minutes, and oxygen and CO_2 ventilatory equivalents were significantly depressed throughout the obstructed period (because minute volume decreased more than oxygen uptake or CO_2 elimination). This suggests that alveolar CO_2 tension increased and alveolar ventilation decreased.

Thompson, S. H. and Sharkey, B. J. (1966). Physiological cost and air flow resistance of respiratory protective devices. Ergonomics, 9, 495-499.

Five healthy young males performed 5 minute treadmill walks at grades of 0, 5 and 10% with and without one of 3 masks (Mask 1: inspiratory resistance (I)=2.3, expiratory (E)=0.72; 2: I=3.0, E=0.65; 3: I=1.5, E=0.93; all in inches of water at 85 l/min flow). At a high workload all masks caused an increase in recovery oxygen consumption. Mask 1 caused an increase after the low workload and Mask 2 caused an increase after the moderate workload. Subjects unanimously selected the mask with the lowest inspiratory resistance but the highest expiratory resistance (Mask 3) as the most comfortable to work with, while that with the highest inspiratory and lowest expiratory resistance (Mask 2) was considered least comfortable.

Van Huss, W. D., Hartman, F., Craig, F. N., and Steinhaus, A. H. (1967). Respiratory burden of the field protective mask under exercise load (Abstract). Federation Proceedings, 26, 721.

Thirteen highly trained university trackmen wearing army boots and fatigues performed timed 1/2 mile runs and 10 mph, 0% grade treadmill runs to exhaustion under four conditions: bareheaded, with M-17 mask with filter bypassed, with M-17 mask using filter, and with M-17 mask plus M-6 hood. There were progressive significant increases in 1/2 mile time (from 157 sec bareheaded to 166 sec with mask and hood) and decreases in treadmill endurance (from 449 sec bareheaded to 328 sec with mask and hood). Exercise pulse rates decreased in proportion to the magnitude of the added respiratory resistance.

Wenger, C. B. and Santee, W. R. (1986). Respiratory problems encountered with M17 mask during testing in a hot-humid environment. Unpublished memorandum.

Seven soldiers wore the M17 gas mask along with other protective clothing while performing intermittent exercise in a 29°C environment with 85% relative humidity (conditions soldiers can be expected to encounter). After 54 minutes in this environment subjects started to complain of ammonia odor or taste, eye irritation, and breathing difficulties. A repeat test with masks without outlet valves still elicited similar complaints from some subjects. The investigators state that apparently such problems have been previously known to occur with this mask, but none of them had been aware of it.

MOPP Gear

Atterbom, H. A. and Mossman, P. B. (1978). Physiological effects on work performance of vapor-barrier clothing and full-face respirator. Journal of Occupational Medicine, 20, 45-52.

Three males were studied with and without vapor-barrier clothing including a full face respirator while performing a series of exercise protocols on bicycle ergometers. The suits caused decreased work performance (a decrease of 28%), aerobic metabolism (VO2max down by 12%), and tolerance time (down by 14%). Even at rest, there were increases in heart rate (10%) and skin temperature (2%), and oxygen consumption was reduced (10-12%). An expanded follow-up study was planned.

Avellini, B. A. (1983). Physiological evaluation of chemical protective clothing (Technical Report No. 151). Natick, MA: Navy Clothing and Textile Research Facility.

Volunteers performed up to 3 hours of work in comfortable, warm humid, hot humid, hot humid with wind, and hot dry environments. They wore one of the following: standard U.S. Army utility uniform with butyl boots and gloves and Navy Mark V mask; the British Mark III CW outfit; or the Norwegian Helly-Hansen CW garment. Each outfit was worn 3 ways: alone, with an impermeable wet-weather cover, or with that and a wettable over-cover. The least stressful CW ensemble was the Mark III alone. The most stressful were the Norwegian and Mark III with wet-weather overgarment. The outer wettable cover decreased heat stress somewhat as did the presence of wind. In the comfortable environment (22.2°C) subjects were able to complete the 3 hour of work in all outfits and the maximum increase in rectal temperature rise was about 1.2°C. (Note: This suggests that, with our protocols, elevated core temperature should not be a problem.)

Belyavin, A. J., Gibson, T. M., Anton, D. J., and Truswell, P. (1979). Prediction of body temperatures during exercise in flying clothing. Aviation, Space, and Environmental Medicine 50, 911-916.

Eight unacclimatized males performed work of various intensities (about 30 to 100 W) alternating with rest for up to 4 hours duration while wearing either the standard helicopter summer aircrew equipment assembly or the standard helicopter summer nuclear biological chemical protective aircrew equipment assembly. There were two environment (H1: dry bulb temperature (t_{db}) of 31°C and a wet bulb temperature (t_{wb}) 25°C; H2: t_{db} of 28°C, t_{wb} of 22°C; both with relative humidity of 50%, and windspeed of 2.6 m/s. Radiant heat corresponding to a globe temperature of 38o^{2}C in H1 and 35°C in H2 was added during the lightest exercise periods. Exercise was stopped if the core temperature (thermistor in the external auditory canal near the ear drum, insulated with cotton wool) reached 38.5°C and the test was terminated if it did not drop below 38.3°C during the next rest period.

Generally, subjects wearing NBC equipment were unable to complete the tests. Equations were derived from the data to predict core and skin temperatures from starting temperatures, level of exercise, duration of exercise, radiant heat load, and various factors related to clothing, environment, and subject. Prediction curves were given for the changes seen during the first 80 minutes of the experiment under the different environmental, work, and clothing conditions. These curves indicate that a subject in NBC gear could complete 80 minutes of 50 watts exercise under all the environmental conditions, but, at a level of 100 watts, in the H1 environment or in either environment with radiant heat then core temperature would increase to 38.5°C after about one hour.

Bennion, S. D. (1982). Designing of NBC protective gear to allow for adequate first aid. Military Medicine, 147, 960-962.

Current MOPP gear interferes with medical evaluation including determining vital signs. This article discusses possible modifications to facilitate medical evaluations which are likely to be needed in actual chemical warfare situations. The alterations are as follows:

a) A small pouch in the side of the gas mask or the hood to allow introduction of a thermometer.
b) A small impermeable thin rubber diaphragm over the brachial fossa (elbow) covered by a protective cloth flap to allow for blood pressure and pulse checks.
c) A protective glove with thin rubber protection over the first and second digits to allow more finger sensitivity in checking pulses. This glove would be protected by a heavier glove when the wearer was not evaluating a patient.

Bensel, C. K. (1980). A human factors evaluation of two types of rubber CB protective gloves (Tech. Rept. No. 80-005). Natick, Mass: U.S. Army Natick Research and Development Command.

Subjects performed manual dexterity tasks while bare handed and while wearing butyl gloves with and without leather over-gloves or neoprene gloves with and without leather over-gloves. Dexterity scores were best with bare hands. However, the butyl gloves worn alone did not significantly decrease speed of performance. The other protective combinations did cause significant decrements, but the effects of the neoprene glove worn without leather over-glove were very small. (Note: this study used the same tasks as McGinnis et al., discussed below, plus a rifle disassembly/assembly task. That study did find significant decrements with the butyl glove.)

Brooks, F. R, Xenakis, S. N., Ebner, D. G., and Balson, P. M. (1983). Psychological reactions during chemical warfare training. Military Medicine, 148, 232-235.

A report of psychiatric symptoms which occurred during a 6 to 8 hour chemical warfare combat field exercise. All 70 participants had previous intensive training with chemical protective gear and gas chamber exercises. None the less, 3 experienced sufficiently debilitating symptoms to require removal from the exercise and 11 others experienced significant symptoms but were able to continue after reassurance and relaxation. Symptoms included panic, confusion, dyspnea, and fear. In several cases these symptoms occurred within the first 10 minutes of the exercise. Overall, there were psychological symptoms and behavioral problems in 20% of all the soldiers involved in the exercise.

Carter, B. J. and Cammermeyer, M. (1985). Biopsychological responses of medical unit personnel wearing chemical defense ensemble in a simulated chemical warfare environment. Military Medicine, 150, 239-249.

One hundred and five army personnel participated in an exercise involving wearing MOPP IV gear for 1 to 2 hours while performing medical support activities. Subjects were informed in advance that the purpose of the study was to investigate biopsychological responses to the gear, and each subject filled out a questionnaire immediately after the exercise. Sixty-nine percent reported some response, most often rapid breathing, shortness of breath, or loss of side vision. Seven subjects did not wear the gear as required, 5 subjects did not complete the exercise due to symptoms, and 3 subjects terminated due to difficulties with equipment. There were no significant correlations between demographic characteristics and whether subjects were able to complete the exercise. There were only mildly significant correlations between such characteristics and the presence of specific biopsychological responses.

Carter, B. J. and Cammermeyer, M. (1985). Emergence of real casualties during simulated chemical warfare training under high heat conditions. Military Medicine, 150, 657-663.

One hundred and ninety five medical personnel participated in a 3 day chemical warfare field training exercise. At least 5 MOPP gear related "real casualties" occurred (apparently some other subjects terminated without reporting to the experimenters). Most casualties were related to running in MOPP gear when the WGBT reading was 77.7°F. Signs and symptoms included dry skin, irregular pulse, rapid breathin and shortness of breath. Contributory factors included hay fever, obesity, pain medications, inadequate food and water intake, and sleep deprivation.

Cacioppo, G. M. and Annis, J. F. (1984). Study of sleeping in a chemical protective ensemble in a warfare environment (Technical Report No. 84/006). Natick, MA: U.S. Army Natick Research and Development Center.

This was a pilot study. Two subjects slept overnight in an environmentally controlled room (25°C dry bulb, 20°C wet bulb, approximate RH 65%, airflow 40 feet/minute) while wearing either pajamas, the West German ground crew chemical protective ensemble (CPE), the Canadian CPE, or the U.S. Army standard ground crew CPE. Rectal and skin temperatures, sweat rate, and single channel EEG and EMG were monitored. An auditory alarm was presented for 20 sec 4 times each night to simulate combat noise.

Statistical analysis was not done because of the small sample size. There was no apparent thermal burden from the CPEs based on body temperatures. However, the subjects frequently complained of heat and sweat. Sweat loss increase averaged 52% for one subject and 23% for the other when the CPEs were worn. Sleep latency and times awake were similar in pajamas and any of the CPEs. The amount of slow wave sleep was similarly reduced by any of the CPEs. Subjectively, the subjects reported worse sleep in the US CPE. Unconscious total removal of gloves and/or respirators occurred several times.

Cole, R. D. (1983). Heat stroke during training with nuclear, biological, and chemical protective clothing: case report. Military Medicine, 148, 624-625.

A 25 year old black male sergeant was noted to be unable to follow commands after training for 3 hours, while wearing NBC protective clothing, with intermittent use of the protective mask (under conditions of 80^{O}F, with 84% humidity). He was transferred to a hospital with BP 190/70, pulse 136, respiration 36, oral temp 101.4^{O}F, and rectal temp 106.4^{O}F. No reason for particular susceptibility was discovered. He recovered with cooling and hydration and there were no apparent residual problems. However, if his mental status had been overlooked he could easily have died.

Fine, B. J. and Kobrick, J. L. (1987). Assessment of the effects of heat and NBC protective clothing on performance of critical military tasks (Technical Report No. T11/85). Natick, MA: U.S. Army Research Institute of Environmental Medicine.

Twenty men trained for 2 weeks in tasks similar to those performed by fire direction center personnel. They then performed the tasks for 7 hour periods on 4 successive days. Days 1 and 3 were in standard battle dress at 70^{O}F, 35% relative humidity (RH). Days 2 and 4 were in MOPP gear at 55^{O}F, 35% RH, and 91^{O}F, 61% RH, respectively. MOPP gear, particularly in association with hot conditions, caused a significant increase in errors of omission.

Fine, B. J. and Kobrick, J. L. (1987). Effect of heat and chemical protective clothing on cognitive performance. Aviation, Space, and Environmental Medicine, 58, 149-154.

Twenty-three well trained men performed several sedentary tasks for 7 hour periods under 3 conditions: in army battle dress at 21.1°C, 35% relative humidity (RH); in Mission Oriented Protective Posture (MOPP) clothing at 12.8°C, 35%RH; and in MOPP gear at 32.8°C, 61%RH. MOPP gear alone caused decrements in some task performances during some time periods. MOPP gear with heat stress caused decrements in all task performances and decrements tended to be progressive over the 7 hour sessions. By the end of 7 hours there was a 17 to 23% increase in group error on investigator-paced tasks.

Goldman, R. F. (1963). Tolerance time for work in the heat when wearing CBR protective clothing. Military Medicine 128, 776-786.

Two semi-permeable protective outfits with gas mask and hood were studied in resting subjects under various environmental conditions (85°F with 75% RH, 95°F with 50% RH, or 105°F with 20% RH). All 8 subjects were able to go over 4 hours without reaching a cutoff heart rate of 180 or rectal temperature of 39.5°C (the actual heart rates and temperatures achieved were not given). The same suits, with and without M9A1 gas masks and M4 hoods and or the additional weight of armor, were studied in 4 subjects walking at 2.5 or 3.35 mph (with a 10 minute break every 50 minutes) at either 75°F 50% RH or 95°F 50% RH. At the lower speed and temperature, all subjects could complete over 4 hours with the gas mask and armor. In the higher speed-lower temperature condition, some subjects completed 4 hours. At either speed with higher temperature no subject completed 4 hours. The addition of mask and/or armor, under all conditions except for the low speed-low temperature combination, reduced tolerance time (subjects stopped the test themselves or were stopped because of heart rates >180). Frequently, when a man was stopped because of a high pulse, rectal temperature reached 39.5°F during the recovery period, with temperature continuing to rise for 10 to 15 minutes after a subject stopped walking.

A subsequent field study was carried out under conditions of solar radiation increment of about 10°F with temperatures between 70°F and 90°F and relative humidity between 30 and 75%. Physically conditioned heat acclimated men participated in a 10 day trial rotating through 5 different uniforms (the standard utility uniform or one of two CBR-protective uniforms, with or without gas mask, hood, and gloves), with and without body armor. Subjects walked on a track at 3.75 mph with 10 minute break every 50 minutes for up to 4 hours. At ambient temperatures below 75°, the two protective outfits with mask, hood, and gloves but without armor, did not significantly reduce tolerance time as compared to the utility outfit. At temperatures above 75°F, there were very significant reductions in tolerance, especially when the outfits were worn with mask, hood, and gloves (from about 100 to about 30 minutes).

Hamilton, B. E., Foles, D. and Simmons, R. R. (1982). Performance impact of current United States and United Kingdom aircrew chemical defense ensembles (USAARL Report No. 82-9). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

A study comparing helicopter pilot performance in the U.S. (2-layer, 2-piece overgarment with rubber boots and gloves, and M-24 mask and M-7 hood) and U.K. (MK-5 respirator under helmet, power supply system, hood, one-piece coverall over close-ribbed cotton underclothes, neoprene cowl, and electrically powered filtered blower/ventilator) CD ensembles to the standard flight suit, in a hot environment. Each of 6 subjects wore each suit on different days.

Tests lasted up to 4 hours, with breaks after each hour when the subject could drink fluid ad lib. A 15-20 minute rest in the shade was allowed after 2 hours. Tests were terminated at the subjects request, if there was apparent deterioration in performance or mental status, if rectal temperature exceeded 38.5°C, if rectal temperature was within 0.5°C of skin temperature, if heart rate exceeded 140 for 10 minutes, or if there were mechanical or weather problems. Ambient temperature varied. Temperature means and ranges were not given.

Aviator performance was not significantly degraded by wearing either of the CD suits. Two subjects exceeded the above described heat safety criteria while wearing the U.S. suit. These subjects maintained their performance up until the tests were terminated. No subjects in the U.K. suit exceeded the criteria.

Hamilton, B. E., Simmons, R. R., and Kimball, K. A. (1983). Psychological effects of chemical defense ensemble imposed heat stress on army aviators (Technical Report No. 83-6). Fort Rucker, Alabama: U.S. Army Aeromedical Research Laboratory.

Six male U.S. Army officers wore each of the following during up to 4 hours of flying a helicopter in hot weather: 1) the US. Army aircrew CD ensemble, 2) the UK aircrew CD ensemble, and 3) the standard U.S. Army flight suit. The suits were worn on different days in random order. Portions of the Walter Reed Psychological Assessment Battery (PAB) were administered before and after each flight. Performance did not vary consistently between the suits. However, when subjects were divided by degree of heat stress (slight = those showing no consistent elevation of pulse or temperature; moderate = those showing consistent elevations but less than HR > 140 for 10 minutes, core temperature > $38.5\,^{\circ}$C, or mean skin and core temperature within $0.5\,^{\circ}$C; severe = those removed from the trial because they met one of the preceding criteria) there were differences. Those with slight stress showed better performances than control subjects who spent the day in isolation with little to do. Those with higher stress showed deterioration as compared to baseline performance, as did the control subjects.

Hamilton, B. E. and Zapata L. (1983). Psychological measurements during the wear of the US aircrew chemical defense ensemble (USAARL Report No. 83-7). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

"Abstract: The psychological (as opposed to physiological) effects of wearing a US aircrew chemical defense ensemble were evaluated using 12 male and 12 female volunteers. Half of the males and half of the females wore chemical defense ensembles while the rest wore standard US flight suits as controls. All subjects were administered tests of cognition (math, logical reasoning, target detection, and reaction time) before and after 6 hours of wear in a controlled environment. In addition, subjects rated their mood before and after wear. It was concluded that wearing the ensemble in an undemanding environment degraded affect (mood and activation levels), slightly decreased accuracy and substantially decreased [i.e. improved] reaction times [on correct responses in serial math, target detection, and logical reasoning], especially in females. The most serious impact of the ensemble would seem to be a [9%] decrease in morale among females."

Harnden, P. G. (1986). Fortran program to predict rectal temperature and heart rate response of a person working in MOPP-4 (Technical Note No. 4-86). Aberdeen Proving ground, MD: Human Engineering Laboratory.

This report presents a computer program which predicts heart rate and rectal temperature for subjects doing intermittent work while dressed in MOPP4 gear. Their formula cannot be applied to our data because the lengths of the work and recovery cycles are not fixed, but depend on the subjects response (i.e. a work cycle continues until heart rate and/or temperature reach set limits, and then the rest period lasts until those parameters drop below other limits).

Headley, D. B., Brecht-Clark, J., and Wittenburg, J. (1987). Sustained performance capabilities of crews in standard and protective work ensembles. Unpublished manuscript.

Crews performing artillery operations wearing full protective ensembles in ambient temperatures of about 90°F were only able to work for about 2 hours because of retention of body heat (body temperatures not given). Crews dressed in standard duty uniform could work for 24 hours. Those in protective ensembles also showed much greater latencies to fire rounds than those in standard uniform.

Henane, R., Bittel, J., Viret, R., and Morino, S. (1979). Thermal strain resulting from protective clothing of an armored vehicle crew in warm conditions. Aviation, Space, and Environmental Medicine 50, 599-603.

Subjects performed 90 minutes of bicycle ergometry at a level simulating the energy expenditure of an armored vehicle crew (50 W) with ambient conditions of 35°C (wet bulb 27°C) and wind speed of 1 m/s. The ergometer rested on a platform allowing continuous accurate weighing providing a measure of evaporative rate. Testing was performed nude, in standard French Army combat clothing, and in that clothing with the addition of a heavy protective overgarment and rubber gloves (but no mask). No fluid intake was permitted during the test.

Energy expenditure increased progressively from the nude to the overgarment condition, due to increased equipment weight. sweat rate also increased considerably (from 493 to 1005 g/h). Evaporation was reduced by 22% in the standard outfit and 42% with the overgarment, as compared to the nude condition. body temperatures stabilized after about 50 minutes in the nude condition but increased progressively with clothes (much more with the overgarment). Estimated tolerance time (time to reach a mean body temperature increase of 2°C over resting conditions) was 8 hours nude, 1.9 hours with standard outfit, and 1.4 hours with the overgarment.

An index of water permeability, defined as the ratio of evaporation rate with clothing to that present without clothing was .78, for the standard outfit, and .58, with the overgarment. It was suggested that this might be useful in ranking the physiological strain a given outfit would cause.

Johnson, R. F. and Sleeper L. A. (1986). Effects of chemical protective handwear and headgear on manual dexterity. In Proceedings of the Human

Factors Society 30th Annual Meeting (pp. 994-997). Santa Monica, CA: Human Factors Society.

Manual dexterity was reduced and learning of manual tasks was slower under gloved conditions than with bare hands. Wearing the M17A1 gas mask had no effect on performance.

Joy, J. T. and Goldman R. F. (1968). A method of relating physiology and military performance. A study of some effects of vapor barrier clothing in a hot climate. Military Medicine 133, 458-470.

A chemical biological (CB) protective suit with an M17 gas mask with or without M6 plastic hood and chemically treated gloves was studied during various exercises performed in the field. Subjects were removed as casualties: if they reached a rectal temperature of 39.5°C without symptoms ("not sick"); if they had syncope, vomiting severe abdominal cramps or persistent retching ("heat exhaustion"); or if they collapsed, without syncope, or could not continue ("physical exhaustion"). Ambient temperatures were stated to be "average summer temperatures for temperate zones".

The number of casualties was similar whether or not the hood and gloves were worn. Only 39% of the "heat exhaustion" casualties actually had rectal temperatures $\geq$ 39.5°C, while 71% of the "physical exhaustion" group did. Of the casualties 41% were "not sick", 20% had "heat exhaustion", and 12% had "physical exhaustion" (the remainder stopped for unrelated reasons such as muscular strains). Subjects carrying heavier loads showed greater rises in rectal temperature. Subjects in protective outfits could not drink or eat during the exercises. By the end of 20.5 hours they had lost an average of 4.5% of their body weight from starvation and dehydration. Subjects in fatigues drank 1 liter of water per hour. The only control subject casualty was carrying a very heavy load. Exercises that involved mostly resting with only short bursts of activity did not cause casualties even with protective garments worn for 2 hours.

King, J. M. and Frelin, A. J. (1984). Impact of the chemical protective ensemble on the performance of basic medical tasks. Military Medicine, 149:496-501.

Wearing MOPP-4 gear with regular protective gloves or with a prototype "tactile glove" slowed the performance of basic medical tasks by medical specialists (MOS 91B, skill levels 1 and 2). Practice over 6 days decreased but did not eliminate this decrement. The prototype gloves tended to develop flaws.

Knox, F. S., Nagel, G. A., Hamilton, B. E., Olazabal, R. P. and Kimball, K. A. (1982). Physiological impact of wearing aircrew chemical defense protective ensembles while flying the UH-1H in hot weather (USAARL Report No. 83-4). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Each of 6 male aviators flew a JUH-1H helicopter while wearing each of 3 ensembles: the standard US Army flight suit, The US army aircrew chemical defense ensemble, or the United Kingdom aircrew chemical defense ensemble, in random order. Ambient WBGT temperature ranged from 27 to 35^{o}C. Tests were terminated if heart rate exceeded 140 BPM for 15 minutes, if core temperature exceeded 38.5^{o}C, or if mean skin temperature was within 0.5^{o}C of core temperature. It was found that, if well acclimatized aviators did not preflight and could drink water every hour, they could fly for at least one full load (about 2 hrs) in CD ensembles before any of them experienced heat stress. Beyond this point, those who were heavier for their height and who were over 29 years old were at greater risk of heat stress. Heart rate was found to be a more sensitive indicator of heat stress than core or skin temperatures. Heart rates and core temperatures suggested that the US CD ensemble was somewhat more stressful than the UK ensemble. Mean total time was 4.66 hr in the standard uniform, 4.19 hrs in the UK ensemble, and 4.09 hrs in the US. Mean weight loss was 0.95 kg for standard, 1.29 kg for US, and 1.43 kg for UK (those in UK and standard drank similar amounts of water while those in US drank almost twice as much).

Kobrick, J. L. and Sleeper, L. A. (1986). Effect of wearing chemical protective clothing in the heat on signal detection over the visual field. Aviation, Space, and Environmental Medicine, 57, 144-148.

Male soldiers were tested on sensitivity for detecting visual signals distributed throughout the visual field. Tests were run in fatigues at $70^{o}F$ ambient temperature and 35% relative humidity (RH), and in MOPP gear at either $55^{o}F$/35% RH or at $91^{o}F$/61% RH. MOPP IV gear significantly increased overall reaction time for signal detection particularly for stimuli in the peripheral portions of the visual field. Exposure to heat caused further deterioration. However, there was no progressive cumulative effect over the 8 hour testing sessions.

Martin, H.de V. and Goldman, R. F. (1972). Comparison of physical, biophysical, and physiological methods of evaluating the thermal stress associated with wearing protective clothing. Ergonomics 15, 337-342.

The effects of: US Army fatigues; UK charcoal deposited chemical protective garment; US Charcoal filled foam protective garment; and US two-layer impregnated longjohns, with impregnated fatigues, permeable gloves, and socks on heat retention, sweating, and evaporative heat loss were studied. Tests were done on soldiers and using heated flat plate measurements of the materials and heated copper manikin studies of the outfits. A computer model of human thermal balance using the laboratory results for insulation, water vapor permeability index, and evaporative potential did not correlate significantly with the results based on the human studies, indicating a need for adjustment of the formula. All eight subjects were able to complete 110 minutes of exercise (walking at 3.5 mph for with a 10 minute break after 50 minutes) in all the outfits without gas mask, except for 3 subjects in the US impregnated longjohns and fatigue outfit who dropped out after 95, 100, and 105 minutes. When the outfits were worn with the M17 gas mask no subjects in the longjohn-fatigue combination and only four subjects in the US charcoal filled foam garment could complete the 110 minutes. Subjects began withdrawing from the test as the body heat storage value reached 80 Kcal, "the usual level at which discomfort becomes acute". Wearing the M17 gas mask

caused an insignificant increase in sweat rate with a significant decrease of 8% ($p<.01$) in evaporation.

McGinnis, J. M., Bensel, C. K., and Lockhart, J. M. (1973). *Dexterity afforded by CB protective gloves* (Technical Report No. 73-35-PR). Natick, MA: U.S. Army Natick Laboratories.

The current (then) chemically impregnated cotton glove, a butyl rubber glove (now standard), and the butyl glove worn under a leather glove were compared to bare hand performance of manual dexterity and firmness of grip tasks. The butyl glove alone performed best of the three protective gloves, even improving firmness of grip. However, it still significantly slowed performance on all the dexterity tasks.

Muza, S. R., Pimental, N. A., and Cosimini, H. M. (1987). *Effectiveness of an air cooled vest using selected air temperature, humidity and air flow rate combinations* (Technical Report No. T22-87). Natick, MA: U.S. Army Research Institute of Environmental Medicine.

Following 4 days of heat acclimation, 6 subjects attempted 4, 300 min heat exposures. Subjects worked at low (175W) and medium (315W) rates, in a climactic chamber kept at 49°C dry bulb, 20°C dew point, 1.1 m/sec wind speed, while wearing chemical warfare protective clothing over a combat uniform, protective vest, and the USANRDEC air-cooled vest. Four combinations of dry bulb (22.5-27.5°C) and dew point (15.5-21.1°C) and flow rates (10 or 14.5 cfm) were supplied to the vest. Results were compared to control and experimental results from an earlier study using a different cooling vest (Pimental et al., *Aviation, Space, and Environmental Medicine* 58:119-124, 1987). These various conditions reduced but did not prevent body heat storage, improving endurance time. At the higher metabolic rate this vest was less effective than that previously tested. However, that vest required a large capacity air conditioning system and large filters and blower units to be installed in vehicles where the vests would be used.

Rakaczky, J. A. (1981). The effect of chemical protective clothing and equipment on combat efficiency (Technical Report No. AMSAA-TR-313). Aberdeen Proving Ground, MD: Army Material Systems Analysis Activity.

A data base was developed as the first stage in a program to assess the effects of chemical protective clothing on combat efficiency. Additionally computer simulation programs used to evaluate doctrine, training procedures, equipment and battlefield scenarios were modified or developed to include the effects of chemical warfare. (This information was given in a draft interim note released January 1981. The following is from a later report released November 1981 under the same report number.)

Tables of estimates of performance efficiency (time required to complete selected maneuvers) of various types of military units without protective clothing and in MOPP4 protective gear at 20^{O}, 50^{O}, and 85^{O}F are presented. These estimates were based on work rest cycles designed to generate negligible heat casualties at a given work level (low = 150 Kcal/hr, moderate = 200 Kcal/hr, or high = 400 Kcal/hr) and temperature (humidity is not addressed). In MOPP4 gear at 21^{O}C (70^{O}C), the closest approximation to our laboratory conditions, it is suggested that: at low work levels any reasonable work/rest periods will suffice; under moderate work levels 40 minutes work/20 minutes rest is recommended; and under heavy work conditions 20 minutes of work/25 minutes of rest is recommended.

Rauch, T. M., Banderet, L. E., Tharion, W. J., Munro, I., Lussier, A. R., and Shukitt, B. (1986). <u>Factors influencing the sustained performance capabilities of 155MM Howitzer sections in simulated conventional and chemical warfare environments</u> (Report No. T11-86). Natick, MA: U.S. Army Research Institute of Environmental Medicine.

A 24 hour live fire scenario, sustained operation protocol was used. Subjects performed selected tasks from the Army Training and Evaluation Program 6-100, either in battle dress uniform or in MOPP4 gear. Average daytime temperatures ranged from 94 to 105^{O}F. A performance assessment battery was used to assess psychological status prior to starting the field test, at 6 hr intervals during the test, and at completion or termination of the test. MOPP4 trials had to be terminated after about 2 to 4 hours because of "medical casualties", those who voluntarily withdrew or who were withdrawn by the medical team (medical criteria were not given in the report). Perceptions of psychological rather than muscular fatigue were the primary factors found to affect and correlate with sustained artillery performance. MOPP4 endurance was chiefly limited by symptoms related to breathing difficulties and thermal discomfort. Casualties reported a greater tendency to tire quickly, perceived their duty position to be less stressful, and expressed greater motivation to volunteer for the study because of the challenge than survivors.

Rauch, T. M., Witt, C., and Banderet, L. (1986). The effects of wearing chemical protective clothing on cognitive problem solving (Report No. T18/86). Natick, MA: US Army Research Institute of Environmental Medicine.

Subjects performed cognitive problem solving tasks over 24 hours of testing. Wearing MOPP level 4 significantly impaired speed of cognitive problem solving compared to MOPP 2 and NC-MOPP conditions.

Rich, L. T. (1985). Analytical evaluation of current United States Army guidelines for soldiers wearing NBC protective overgarments under various environmental conditions (no report number given). Alexandria, VA: HQDA, MILPERCEN (DAPC-OPPA-E).

This report evaluates the US Army MOPP4 chemical protective configuration. Previous safety guidelines (FM 21-40) were found to be inadequate because of failure to consider the important effects of humidity on water loss and body heat accumulation. A previously validated computer model of the human thermal regulatory system was used. Maximal core temperatures for negligible (no more than 5% of workforce likely to be incapacitated) and minimal (less than 25% of subjects at risk for heat exhaustion) were set at 38 and 39°C respectively. Graphs of core temperature vs time and water loss vs time for continuous low (250 watts), moderate (350 watts), or heavy (500 watts) work in MOPP4 gear at various temperatures and humidities were given. Similar graphs for intermittent work using the previously recommended work rest cycles (FM 21-40) were also given. A safety limit for the amount of water that can be lost was presented. Water loss was found to be the limiting factor at moderate temperatures and at high temperatures where only low level work was done.

Smolander, J., Louhevaara, V., and Korhonen, O. (1985). Physiological strain in work with gas protective clothing at low ambient temperature. American Industrial Hygiene Association Journal, 46, 720-723.

Seven experienced fireman and one mechanic in average physical condition performed simulated repair and rescue tasks while wearing an impermeable gas protective suit and a self-contained breathing apparatus. Total work times averaged 37 min and ambient temperature was 2.0°C with wind velocity of 0-4 m/s. Despite the lack of thermal strain, these typical tasks caused marked physiological strain as demonstrated by mean heart rates of about 147 bpm and weight losses from sweat of 300g. The mean rectal temperature increased by 0.8°C. Workers who use such equipment must be physically fit. (Note: Protective clothing plus SCBA may be analogous to MOPP 4 plus a back pack.)

Smolander, J., Louhevaara, V., Tuomi, T., Korhonen, O., and Jaakkola, J. (1984). Reduction of isometric muscle endurance after wearing impermeable gas protective clothing. European Journal of Applied Physiology, 53, 76-80.

Male subjects walked at 21% (L) or 41% (M) of VO2max for 25-30 min, at an ambient temperature of 24°C, while wearing an impermeable gas protective suit and a self contained breathing apparatus. Subsequently heart rate, and rectal and skin temperatures were found to be increased and the isometric endurance of forearm muscles at 40% maximum voluntary contraction was found to be reduced (12% after L, NS; 24% after M, $p<.01$). Ventilating the suit with 28 l/min of room temperature air did not change these effects.

Stephenson, L. A., Kolka, M. A., Allan, A. E., and Santee W. R. (1987). *Heat exchange during encapsulation in a chemical warfare agent protective patient wrap in four hot environments* (Technical Report No. T10-87). Natick, MA: U.S. Army Research Institute of Environmental Medicine.

Eight male subjects were studied during encapsulation in a Chemical Warfare Agent Protective Patient Wrap in each of four environments: 1) average ambient temperature (Ta) 54.7^{o}C, average dew point temp (Tdp) 21.7^{o}C, average black globe temperature (Tg) 68.3^{o}C; 2) Ta 42.7^{o}C, Tdp 32.5^{o}C, Tg 56.3^{o}C; 3) Ta 41.8^{o}C, Tdp 11.3^{o}C, Tg 57.5^{o}C; 4) Ta 35.7^{o}C, Tdp 27.7^{o}C, Tg 50.5^{o}C. All conditions had average irradiance of 1152 W/m^{2} and wind speed of 0.5m/s. The dry insulative value of the wrap was 1.44 clo and the permeability index was 0.25. Subjects remained wrapped until they requested removal or until heart rate exceeded 160 bpm for 5 consecutive minutes. Average encapsulation times in the four environments were 37, 49, 62, and 62 minutes, respectively. So safe encapsulation time is severely limited in hot environments (either wet or dry), when a solar heat load is included.

Tharion, W. J., Rauch, T. M., Munro, I., Lussier, A. R., Banderet, L. E., and Shukitt, B. (1986). *Psychological factors which limit the endurance capabilities of armor crews operating in a simulated NBC environment* (Technical Report No. T14/86). Natick, MA: U.S. Army Research Institute of Environmental Medicine.

Twenty-seven male soldiers participated in armor field tests wearing normal field clothing (NO MOPP condition), MOPP4 gear (MOPP4 condition: modified M-25 mask with drinking tube, rubberized boots, gloves, and a standard overgarment), and MOPP4 gear after training in coping strategies and with the opportunity to eat (FIX condition). Tests were terminated when 2 of 4 crewmen withdrew voluntarily or were removed by the medical monitor. These subjects were termed "casualties", while the remaining crewmen were "survivors". A computerized performance assessment battery was administered several days prior to the field test, 6 hours into the field test, and after termination of the field test.

Casualties in the MOPP4 condition exhibited significantly greater depressive tendencies on the pre-test battery than survivors. No depressive difference was found between casualties and survivors in the FIX condition. Casualties reported more intense feelings of sleepiness and dizziness and exhibited a significantly greater level of anxiety. They also complained of more respiratory distress, mental fatigue, thermal stress, general fatigue, gastrointestinal distress, and muscle exhaustion. Survivors had a higher impression of the crew as a functional unit (crew atmosphere).

There were no sleepiness, dizziness, anxiety, or crew atmosphere differences among the different testing conditions (NO MOPP, MOPP4, FIX). Subjects in the MOPP4 condition as compared to the FIX condition perceived more respiratory distress, mental fatigue, muscle exhaustion, and general fatigue.

They conclude that perception of respiratory distress or discomfort imposed by wearing the mask are important in limiting work tolerance or endurance, as is thermal distress. Additionally, high anxiety or more depressed types are more likely to exhibit such distress. Coping strategies, opportunity to eat, and previous MOPP4 experience may all improved endurance under MOPP4 conditions.

Thorton, R., Brown, G. A., and Redman, P. J. (1985). The effect of the UK aircrew chemical defence assembly on thermal strain. Aviation, Space, and Environmental Medicine, 56, 208-211.

Chemical protective clothing was found to impose a thermal strain (core temperature > 37.6°C, dehydration loss = 1% body weight) when worn for 2 hours in an environment with dry bulb temperature of 35°C and wet bulb temperature of 19°C and a wind speed of 2.0 m/s. These effects occurred in subjects simulating the activity level of crewmen but not in those simulating the lower activity level seen in pilots. Personnel conditioning to prepare for such heat stress is recommended.

Vittorio, P. V. and Cattroll, S. W. (1975). _Dexterity afforded by CW protective gloves_ (Technical Note no. 75-21). Canada: Research and Development Branch of the Department of National Defence.

"The effects on manual performance of an experimental Canadian CW protective glove and US and UK CW protective gloves were compared using five different manual tasks. The results show that, statistically, performance in three of the manual dexterity tasks was significantly better with the US CW protective glove than with the Canadian or the UK CW protective gloves and in the same three tasks there was no significant difference in performance between the latter two gloves. Although the difference shown is statistically significant, its practical effect in the performance of military tasks may not be great."

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This is an annotated bibliography of papers which relate to the characteristics and effects of gas masks and other chemical defense gear. Psychological, physiological, and cognitive performance effects are included. Keywords:

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